SIGNAL COHERENCE STUDIES IN MULTIAPERTURE ARRAYS

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The gain capability of a single-aperture antenna is limited by surface tolerance. Figure 1 is a plot of gain versus antenna diameter, normalized to wavelength. The lower curve indicates the state of the art in single-aperture antenna gain in 1965. The upper curve represents the current state of the art as defined by the antennas listed on the figure. Although 73-dB gain is technically feasible, the antenna cost increases exponentially as the antenna size enters the nonlinear portion of the curve. In this region, it becomes economically desirable to array several smaller aperture antennas, each of which falls in the linear portion of the curve, instead of constructing a single large antenna.

Each time the number of array elements is doubled, the gain requirement of each antenna is theoretically reduced by 3 dB. The feasibility of arrays is dependent upon the ability to achieve close to the theoretical gain improvement through coherent combination of the array elements. The importance of this factor has prompted the construction of a two-element array to measure the gain improvement that can be realized while tracking spacecraft. These measurements were taken at VHF and at S-band.

The array at VHF consisted of two five-element Yagi subarrays shown in Figure 2. One of these Yagi antennas is shown at the left, the second Yagi antenna is barely noticeable in the distance. At S-band, two 4.6-m diameter reflectors were used with focal point mounted monopulse feeds. At each frequency, the gain improvement of the array over that of a single element was determined by measuring CNR at the output of the coherent combiner and comparing this to the CNR at the input channels. These gain improvement measurements were repeated at 20-s intervals for the duration of the satellite pass. ATS 3 was used as the transmitter at VHF, and Apollo 12 at S-band.

Since these measurements indicate "instantaneous" CNR in each channel, the randomness of the noise in the input channels generally resulted in unequal CNR's at these points. For any given set of measurements, the maximum theoretical CNR (gain) improvement at the output over that of the best input channel is defined by the relative CNR between input channels. The measured gain improvement fell within 0.5 dB of the theoretical maximum with 90-percent probability at VHF and 93-percent probability at S-band.

Unless time delay correction is included in the system, the spacing between array elements will cause a reduction in the bandwidth capability of the array. This bandwidth limitation is due to the added path length the signal must travel to be received at the first element as compared to that for the second element. Figure 3 indicates the maximum loss in SNR at band edge versus bandwidth for several antenna spacings. The wider spacings shown in Figure 3 are beyond that required to overcome mutual shadowing and are considered for applications where atmospheric inhomogeneities cause severe phase front distortion. One such application is used at the NASA tracking stations in South America where spatially correlated ionospheric fading at VHF dictates a spacing of at least 300 m for optimum performance.

An automatically controlled time delay correction system has been developed and tested for this program. The time delay circuits were inserted in the IF stage of the coherent receiver. A fixed 2.909-μs delay was placed in channel 1 and a variable delay circuit was placed in channel 2. The variable delay is digitally selectable in increments of 90.9 ns (one wavelength at IF) with a maximum delay of 5.808 μs. The setting of the variable delay unit is calculated from the azimuth and elevation of the spacecraft, which uniquely define the required delay for any given antenna separation. The calculation requires 25 ms, but the actual switching time is less than 50 μs. The variable delay control speed is sufficient for tracking rates of up to 0.05 rps. Incorporation of the time delay system into the receiver had no measurable effect on receiver phase or AGC.

The effect of using this time delay system is to extend the bandwidth capability of a two-element array for any spacing up to 850 m to that which would be available with no time delay system at a 15-m spacing, a bandwidth extension of 50 times.

In summary, arrays of large aperture antennas are a feasible solution to the problems posed by the technical and economic limitations of single aperture antennas, and these large arrays can operate within at least 0.5 dB of their theoretical gain capability. The greatest disadvantage of multi-aperture arrays, bandwidth limitation, can be essentially eliminated if digitally controlled time delay correction circuits are used.

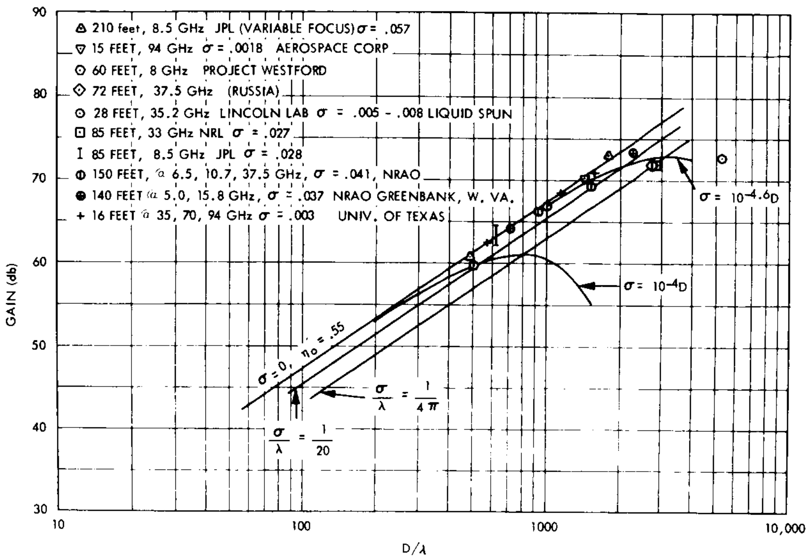

Figure 1—Antenna gain versus surface tolerance.

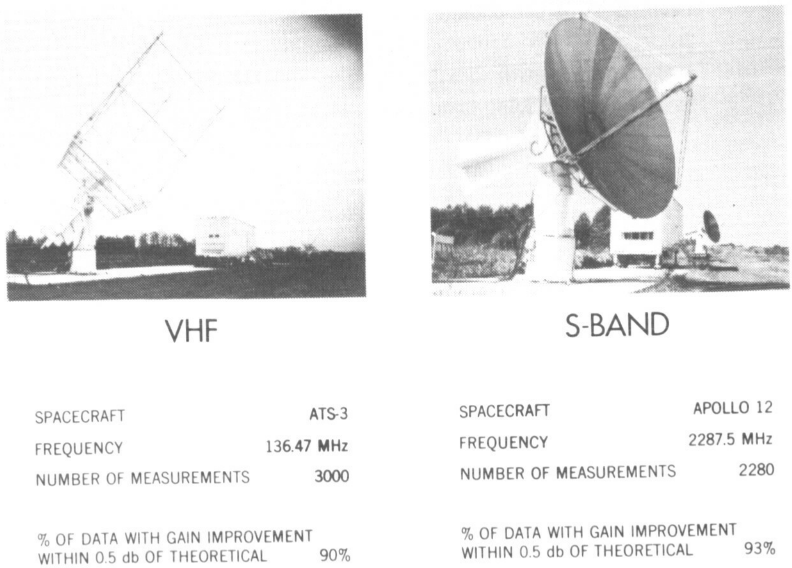

Figure 2–Measured gain improvement.

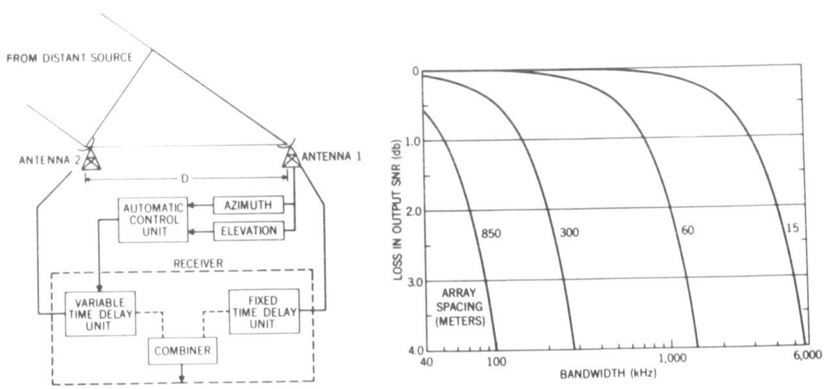

Figure 3–Array bandwidth.